



Methods of Manufacturing Aeroelasticity Bench Test for NACA0012 Wing Model in the Low Speed Wind Tunnel

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To cite this article:

Thi Tuyet Nhung Le, Thanh Phat Duong, Nhat Truong Hoang. Methods of Manufacturing Aeroelasticity Bench Test for NACA0012 Wing Model in the Low Speed Wind Tunnel. *International Journal of Transportation Engineering and Technology*. Special Issue: Experiments Researches in Aeronautical Engineering. Vol. 2, No. 5-1, 2016, pp. 7-11. doi: 10.11648/j.ijtet.s.2016020501.12

Received: August 16, 2016; **Accepted:** August 22, 2016; **Published:** September 19, 2016

Abstract: The purpose of this study is to take measures to manufacture the experimental model: NACA 0012 wing model in the low speed wind tunnel (38 m/s). The parameters base on the achieved results of Thi-Tuyet Nhung Le & al.: “Design of aeroelasticity bench test for NACA0012 wing model in the low speed wind tunnel: Influence of wing’s parameters on flutter speed”. As flutter is a destructive phenomenon, many studies has researched and manufactured experimental models. The suitable material of wing is polyurethane elastomer. The suitable method which manufactures the wing model is CNC method.

Keywords: Methods of Manufacturing, Aeroelasticity, Bench Test for NACA0012

1. Introduction

The study of flutter and aeroelasticity in general is of utmost importance to the aerospace industry in the early days of flight. Two historical failure cases are indicative of the two major aeroelastic failure modes: static instability and dynamic instability [1]. The first recorded and documented occurrence of aircraft flutter was the Handley Page O/400 bomber in 1916 by F. W. Lanchester. This is an example of a combination of two or more modes of vibration coalescing to extract energy from the airstream to create flutter. The case of the Langley flyer failure points to a case of static aeroelastic of the wing structure once the aerodynamic forces caused the wing to twist beyond the structural restoring moment capacity [1]. Therefore, research about aeroelasticity phenomenon in aircraft design is very important. The purpose of this study is to describe some preliminary experimental work that has been carried out in an attempt to manufacture aeroelasticity bench test for NACA0012 wing model. This model is fabricated to observe and study about static aeroelasticity (divergence) and dynamic aeroelasticity (flutter) phenomenon in the low speed Ho Chi Minh City University of Technology wind tunnel facility with the cross sectional area of 400 x 500 mm, the

length of 1000 mm and the maximum velocity of 38 m/s.

In our study, the geometric parameters and materials of NACA 0012 wing model are based on Strip theory [2] and V – g method [3] that are in Hoang Nam Vang’s thesis [4], and dimensional analysis in Tuan Anh Nguyen’s thesis [5]. Dimensions of this wing are specified according to the wind tunnel available for the flutter test. With achieved results, the suitable material of the wing is polyurethane elastomer and it has the flexible shaft made of epoxy.

As flutter is a destructive phenomenon, many studies has researched and manufactured experimental models. Roberto Gil Annes has designed a flexible wing for flutter active control studies [6], in which the flutter speed was found by using NASTRAN and ZAERO softwares. Roberto constructed three wing models with the same dimension but different materials. However, the dimensions of the models were inexact. Besides, Kassem has researched flutter and divergence characteristics of a composite plate wing [7]. The flutter and divergence velocities were obtained using V-g method. The wing was idealized by a rectangular cantilevered composite plate with uniform thickness. It was created by interconnected aluminum alloy beams.

Based on analysis and survey, CNC methods [8] and injection molding method [9] are the most suitable methods.

CNC and injection molding methods fully meet the technical requirements during the experiments. However, the cost of injection molding method is very high. Whereas, CNC method with a small charge is more appropriate. At the same time, this study designed wing racks for laboratory and surveying costs for manufacturing NACA 0012 wing.

2. Theoretical Analysis

2.1. Applications of Strip Theory to Calculate the Static Aeroelasticity

Based on the theory of cross-sectional area in two dimensions, the theory of three-dimensional wing was built. Normally, we use two methods which are the strip theory and panel methods to calculate the static aeroelasticity.

Then, the divergence airspeed is:

$$V_D = \sqrt{\frac{2q_D}{\rho}} = \sqrt{\frac{\pi^2 GJ}{2\rho_\infty l S e \frac{\partial C_L}{\partial \alpha}}} \quad (1)$$

With a rectangular wing, if the necessary parameters that are length, L ; chord, c ; torsional stiffness, GJ are available, the divergence speed, VD can be calculated by the formula (1). Hence, we can design an aircraft's wing according to the parameters, which are found and they are suitable to the speed of the wind tunnel, which has known.

2.2. Solving Flutter Problem by V-g Method

In this section, the problem of dynamic instability is concentrated mainly in that particular flutter phenomenon. Flutter is a phenomenon mechanical vibrations dynamic instability; the wing structure will be destroyed when aircraft move over critical velocity. Flutter phenomenon occurs under influence of the three forces: inertia forces, elastic forces and aerodynamic forces. In this article, $V - g$ method is used to calculate the necessarily velocity at which flutter phenomenon occurs through Eigenvalues problem. Based on the $V - G$ method, the necessary velocity at which flutter phenomenon occurs through the Eigenvalues problem can be figured out.

$$V_F = \frac{b\omega_\alpha}{k_F \sqrt{X_{real}}}$$

Thus, to calculate the velocity Flutter the parameters that need to be identified include:

- Frequency mode oscillation in two separate pure bending and twisting of the wing is pure and, their values are determined through structural simulation software channel on Abaqus
- The distance from the center to the elastic center
- Location of elastic mind from the aerodynamic center is characterized by infinite distance dimensions of elastic center and a point between the wires.
- Radius dimensional array of mass moments of inertia.

2.3. Modeling and Results

From the theoretical of static aeroelasticity and dynamic aeroelasticity, the geometric dimensions of model is built to fit with the size of wind tunnel. The velocity divergence and velocity flutter must be less than the maximum speed of the wind tunnel 38 m/s.

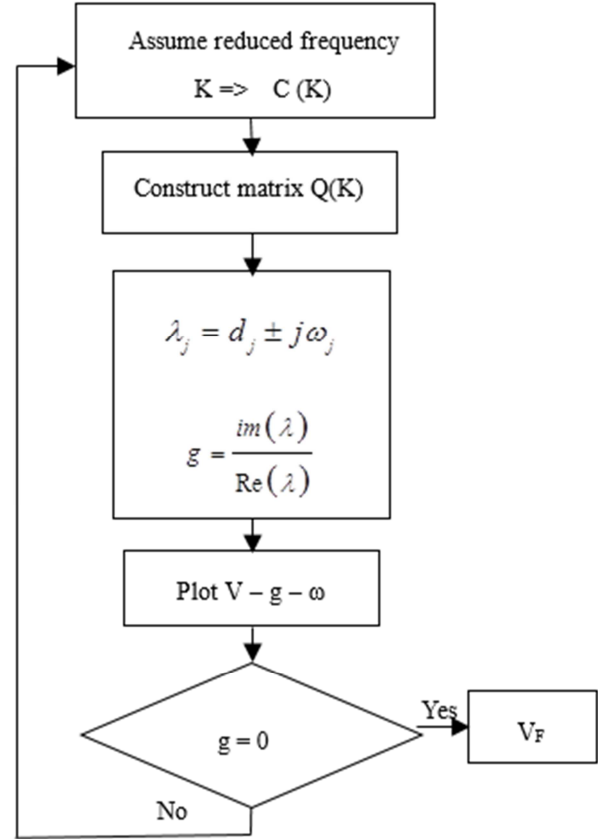


Figure 1. Calculate flutter velocity diagram.

Dimensionless analysis of the wing's parameters were carried out, and the ratio of Flutter velocity dimensionless $V_F/b\omega_\alpha$ versus damping "g" was presented in "Fig. 2". At those precise values:

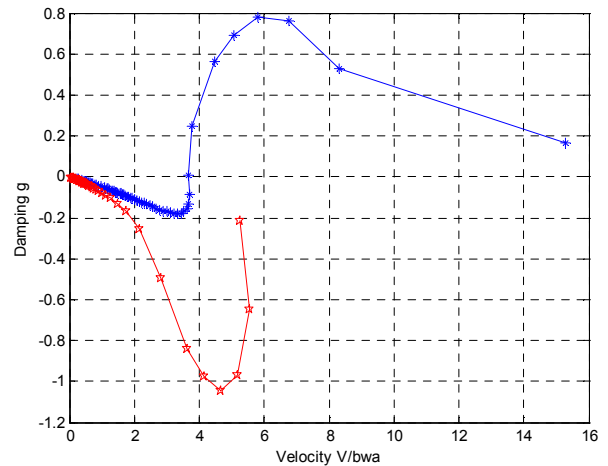


Figure 2. The graph of velocity.

The flutter speed is obtained at the point where value of “g” for the structure is zero

$$\frac{V_F}{b\omega_\alpha} = 3.68$$

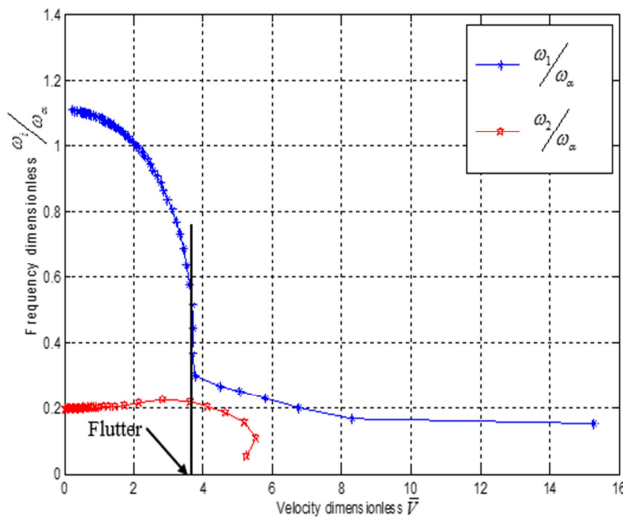


Figure 3. The graph of velocity versus ratio frequency.

Based on the graph, the Flutter velocity for different oscillation frequency of systems can be identified by simulating them on the finite element software.

Results:

Wing models and its shaft are made of polyurethane elastomer and epoxy respectively.

The geometry and material of the wing pattern is selected as follows:

- Chord length: $c = 10$ cm.
- Wing span: $l = 40$ cm.
- Position from center front edge aerodynamic wing: 2.5 cm.
- Position from center front edge elastic wing: 3.5 cm
- Position of the center of gravity from front wing edge: 4.2 cm.

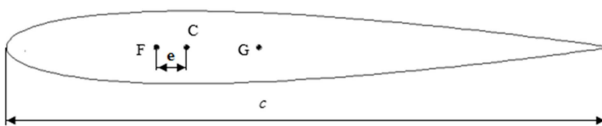


Figure 4. Airfoil $c = 100$ mm.

3. Methods for Machining NACA 0012

3.1. Popular Methods

There are many methods of manufacturing the wing. Three popular methods are milling by using CNC machines, injection molding (the most popular molding) and 3D printing. Each method has particular advantages and disadvantages. Hence, it is vital to analyze the pros and cons of these three methods before choosing the most suitable technique. Here is a comparative table analyzing the pros and cons of the three methods.

From the table 1, it can be clearly seen that injection molding and 3D printing have several drawbacks. Specifically, the price of the former is extremely high, and it requires an enormous quantity of products. The only issue of the latter relates to the dimension. The capacity of this technique is quite small and impossible to satisfy the requirement. Regarding the last method – milling, it is obvious that this technique has several advantages over the first two and it meets the technical requirements with the acceptable price. Consequently, the first two methods are eliminated and the last one is chosen to manufacture the wings.

3.2. Milling Method

3.2.1. CAD/CAM Process

a) Methods of CNC programming CAD

There are two basic ways to program CNC machines:

- Conversational programming: This is the simpler of the two methods. In effect, this is a macro programming language used to instruct the machine to perform pre-programmed cycles (i.e. facing, drilling holes in arrays, etc.). When writing a conversational program, you enter the appropriate parameters associated with each machining cycle. This is analogous to using the polar array function in SolidWorks; you don't have to do the layout or trig to find the location of the features, you just specify the essential parameters and the software does the rest for you.
- CAM programming: This is the more powerful of the two methods. Using this method, you import your part model into a CAM (computer aided manufacturing) program and define the parameters associated with each and every machined feature on the part. These parameters include tool diameter and length, depth of cut, tool path geometry, etc.

Table 1. The comparative table of 3 methods.

	methods		
	Injection	3D printing	Milling
Accuracy	High	high	high
Product surface	Meet the technical requirements	not sharp	good
Dimension	Appropriate	small, the biggest dimension: 200x200x200 mm	adequate
Price	high: 20-30 million VND	low	low
Quantity requirement	Bulk	not required	not required
Other features	Can reuse mould		

CAM programming is preferable because the CNC machine with CAM programming is available in our laboratory.

b) CAM programming steps.

- Create a solid 3D model of the part to be produced.
- Import the solid model into the CAM (computer aided manufacturing) software.
- Input the raw material stock size and set the virtual part's coordinate origin.
- Input the necessary information for each tool used in machining the part features; typically, a tool library will exist, which is simply a database of tools and their related parameters.
- For each part feature, select the appropriate tool from the library and set the parameters necessary for machining that feature; typical parameters include spindle speed, depth of cut, feed rate, number of passes, tool path pattern, etc.
- Verify the programmed tool path(s) by running the CAM software's virtual machining cycle.

3.2.2. Actual Manufacturing Process by Using CNC Machine

a) Materials and tools:

Materials: rectangular polyurethane elastomer block with dimensions: 500x170x20 mm and 3-kilogram plaster.

Tools: CNC machine, 1 ball mill and 1 end mill with diameter of 6 mm and 10 mm.

b) Technical issues

Some technical issues below need to be considered carefully:

- The CNC machine is only able to machine materials which have the flat bottom surface. However, the wing has 2 curved surface. Consequently, the wing is unable to be fixed during the process of machining the second surface. Thus, after finishing milling the first surface, a filler, such as plaster material, is used to fulfil this surface. This process aims to keep the below surface flat in order to support the milling of the second surface.
- The material is polyurethane elastomer, which is thermoplastic. This kind of materials is soft and easily bendable when it is heated. Hence, during the manufacturing, the cutting speed is pretty low, approximately 1500 m/min.



Figure 5. The wing NACA 0012 manufacturing by using CNC machine.

4. Conclusion

Based on the parameters in the previous thesis, a two-degree of freedom aeroelastic test bench has been manufactured. The paper presented the aeroelasticity bench

test manufacturing process and optimize this process. The suitable material for the wing is polyurethane elastomer and it has the flexible bar made of epoxy. The suitable method to manufacture the wing model is CNC method.

The development of the project: carry out an experiment on aeroelasticity in a low speed wind tunnel.

Acknowledgements

The authors would like to thank the Vietnam Training Program of Excellent Engineers (PFIEV) at Ho Chi Minh City University of Technology for its financial support. This article was introduced in 6th Scientific Research Conference of PFIEV – HCMUT Students, Ho Chi Minh Univ. of Technology, Viet Nam, 2016.

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Biography



Thi Tuyet Nhung Le (1983, Vietnam) PhD in Mechanics & Materials (2012, Predicting Behaviour law of BMC composite using multi-scale homogenization method) – Arts et Metiers Paristech (ENSAM-Paris), Engineer in Aeronautics of ENSMA-Poitiers, France. Lecturer and Researcher at Department of Aerospace Engineering, Ho Chi Minh City University of Technology, Vietnam. Research experience: Composite material, Aero-elasticity, Multi-scales modelling, Damage behaviour, Fatigue, Fracture mechanics, Computational Structure Dynamics. Publications: 4 publications in scientific and professional journal and 3 papers on conference proceedings.



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